

7.—Land Forms and Soils in the Avon Valley, near York, Western Australia

By R. L. Wright*

Manuscript received—19th September, 1961

Four stages of downcutting and base-levelling are recognised between a deeply weathered surface and the main channel in part of the Avon valley, Western Australia. Corresponding to the first three stages are two rock-cut terraces and a double phase alluvial terrace. The fourth stage is represented by a later incision of the Avon and its tributaries.

The form and distribution of remnants of the deeply weathered surface and the terraces are described in detail, and the relationships and regional extent of the land forms recognised in the field are further illustrated by cartographic analysis. This account of the land forms is followed by a discussion of their relationships to the soils of the area which have been previously described by Mulcahy (1959, 1960).

The relationships between soils and erosional and depositional surfaces are shown to be complex. The main conclusions are that most of the soils of the area are the result of geomorphologically relatively recent episodes; that youthful soils can occur on geomorphologically "old" sites; that sites inherited from the same stage of landscape evolution may have different soils; and that similar soils may occur on sites relating to different geomorphological stages.

A denudation chronology concludes the paper.

Introduction

This paper describes cyclic land forms in the Avon valley near York. Field work was confined to that part of the valley between Hamersley and Mount Hardey, however, detailed mapping of land forms was carried out during four weeks' field investigation of a small area shown in Figure 1. The land forms recognised in the field are supplemented by cartographic analysis. Both field mapping and cartographic analysis were concerned only with land forms, however, Mulcahy (1959, 1960) previously mapped in detail the soils of the area with particular reference to their development in relation to stages in the erosion of a lateritised land surface. Therefore, the account of the land forms in the present paper is followed by a discussion of their relationships to the soils as mapped and described by Mulcahy.

The upper Avon follows a north- to north-westerly course on the plateau surface of Western Australia, approximately parallel with the coast and about 60 miles inland. At Toodyay it turns south-west through the escarpment and reaches the coast near Perth. The plateau surface in this area was named the Darling Plateau or Peneplain by Jutson (1912) and it is bounded on the west by the Darling Scarp. It lies mainly between 800 and 1,000 feet above sea-level, rising very gradually eastwards.

The Avon and its tributaries in the York area follow two main directions; north-north-west, corresponding to the strike of the underlying rocks, and north-east or east-north-east, an important jointing and fracture trend (Fig. 2). The Avon valley here forms a trench between 500 and 600 feet above sea-level and a mile or so wide. Away from the river, the landscape is that of a sub-maturely dissected plateau. To the west, dominantly on granite, the plateau is generally between 1,000 and 1,200 feet above sea-level. Where gneiss crops out it is interbedded with discontinuous quartzite bands and other meta-sedimentary lenses (Johnston 1952). These have been etched into bold steep-sided hills such as Mt. Mackie (900 ft.) and Mt. Bakewell (1,500 ft.). On the less resistant gneiss east of the river the plateau is between 750 and 850 feet above sea-level. Rising above, however, are the Needling Hills (1,200 ft.), formed on quartzite, and Mt. Brown (1,000 ft.) and Mt. Hardy (900 ft.) on granite. More resistant lenses in the gneiss show themselves as local slope breaks and minor valley-side benches. Low narrow ridges are formed by granite and dolerite dykes, the most prominent of which have a north-north-west or north-east trend.

Field Methods

The benched valley sides of the Avon are evidence that incision has taken place in stages, with gently inclined surfaces or "flats" corresponding to prolonged periods of base-levelling and steeper linking slopes representing the intervening periods of downcutting. A study of the valley was made to see if stages of downcutting and base-levelling could be recognised.

Field work consisted of the recognition of "flats" and breaks of slope, and mapping them using aerial photographs. In this context "flat" does not imply lack of slope. It is an accepted term as used by many geomorphologists (e.g., Linton 1948). The important considerations in defining "flats" are the delimiting breaks of slope between the "flats" and the steeper linking slopes, and the break of slope at the lower margin of a "flat" is particularly significant. This break is commonly relatively well-defined (see Figs. 3 and 4) and can be measured to within a few yards and mapped with little difficulty. However, mapping is more difficult if this lower break of slope is a convex "curved break of slope" (Savigear 1956). In this case the lower margin of the "flat" is mapped at the measured upslope boundary of the convexity. Slope breaks determined by outcrops of more resistant rocks were distinguished from those

* Division of Land Research and Regional Survey, C.S.I.R.O., Canberra, A.C.T.

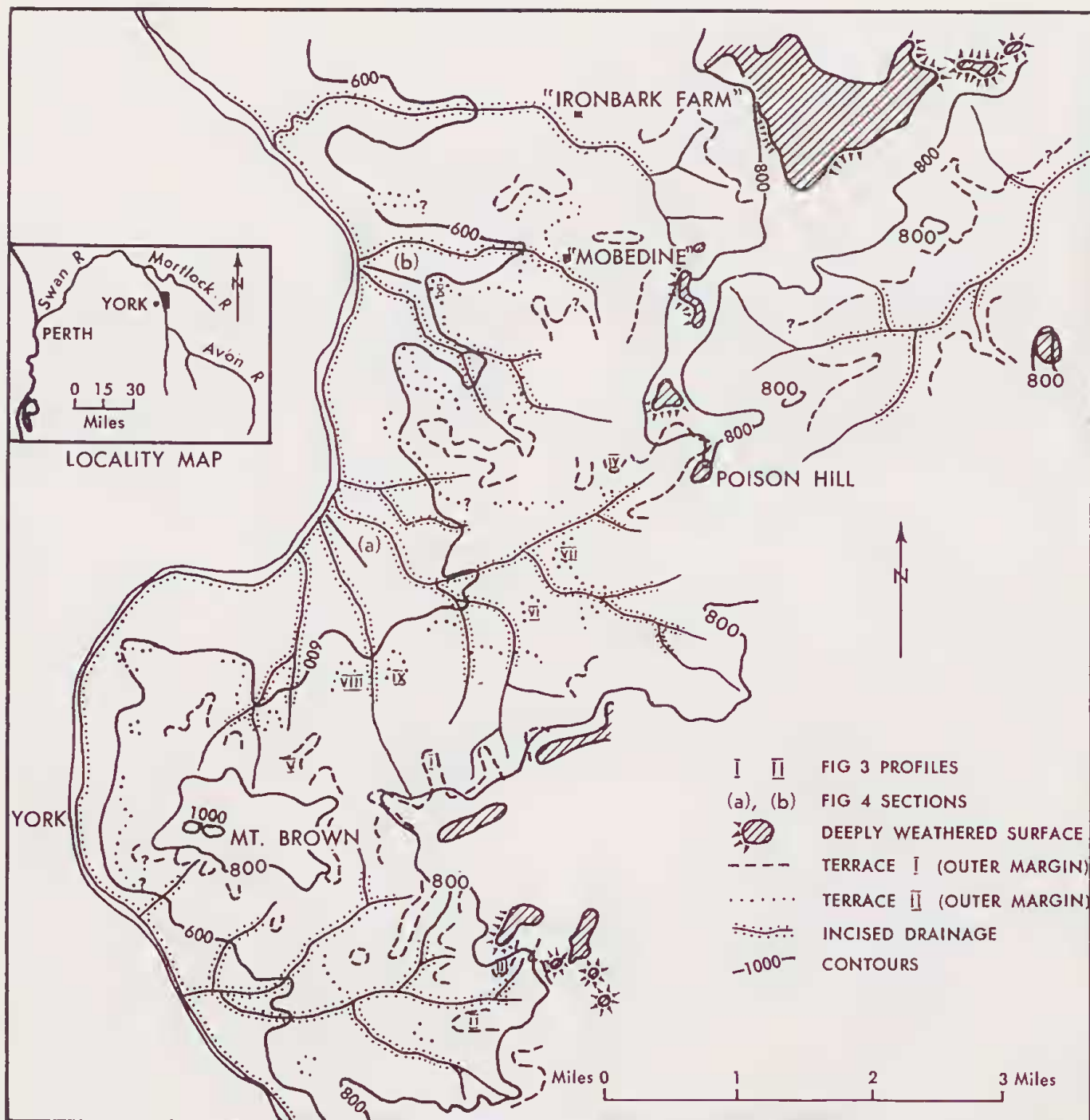


Fig. 1.—Distribution of cyclic elements in the landscape.

which transgressed structure and which were therefore interpreted as delimiting remnants of the sides and floors of former valleys.

Although field mapping was not extended to the Mortlock River, correlation of similarly staged terraces within the Avon and Mortlock catchments was established by their continuity across the watershed at higher levels.

A barometric altimeter was used to supplement map contour data (No. 400 York 1-mile series, Second Edition). Two sections were levelled and other slope angles were measured with an Abney level.

Cyclic Elements in the Landscape

Deeply Weathered Surface

Preserved on the higher parts of the crests of the main interfluvies are the remains of what was formerly an extensive deeply weathered erosion surface, remnants of which are readily recognisable by their laterite cappings, delimiting breakaways, and general accordance of level. Although these remnants have been mapped by Mulcahy they are very restricted in area and, therefore, consideration of them is important if any attempt is to be made to reconstruct the nature of the original surface. Thus, a brief

description is given of the altitudes and forms of remnants in the area of detailed field work.

The largest remnant mapped (Fig. 1) is situated one mile east of Ironbark farm (862653)*, at an altitude of between 800 and 850 feet above sea-level, and forms part of the Avon-Mortlock watershed. The western and northern part of the residual consists of a broad rounded rise between 30 and 40 feet above the remainder, with a flat crest 60 yards wide. On the north and south flanks of the rise, slopes are relatively steep, attaining 4 per cent. Below the rise the surface slopes at 1 per cent. in the west, but elsewhere has no appreciable gradient. The remnant is delimited by break-aways between 10 and 30 feet high with slopes up to 40 per cent., except to the south, where the boundary is a long slope of between 3 and 4 per cent.

Immediately east of this residual, at slightly more than 800 feet above sea-level, is a smaller residual of the deeply weathered surface. Its crest slopes are up to 4 per cent., as on the Ironbark residual, and it is bounded by break-aways only slightly less pronounced than those of the larger residual.

* The figures in brackets are grid references on the York 1-inch map.

To the south of the Ironbark residual are four small remnants of the surface extending in a belt north to south. The northernmost one, east of Modedine (860632), is at a height of 800 feet. The second remnant is at 850 feet and is preserved on an outcrop of resistant rock which may account for it being somewhat higher than the other remnants. The third remnant is slightly less than one mile north-east of Red Knob (870611), and the fourth, worked for gravel, is crossed by the Goldfields Road at Poison Hill (880601).

Three miles east, at Collins Hill, (920623), is another small outlier of the surface at a little above 800 feet. This residual contrasts with other remnants of the old surface in that it has no delimiting breakaways. It is bounded by slopes less than 7 per cent.

East of Mt. Brown is another group of remnants of the old surface. These are generally at a height of 850 feet, but to the south an altitude of 900 feet is reached.

In this area, therefore, remnants of this erosion surface are found only on the watershed between the Avon and Mortlock Rivers and are, with one exception, very small.

These remnants east of the Avon are cut in gneiss and are between 800 and 900 feet

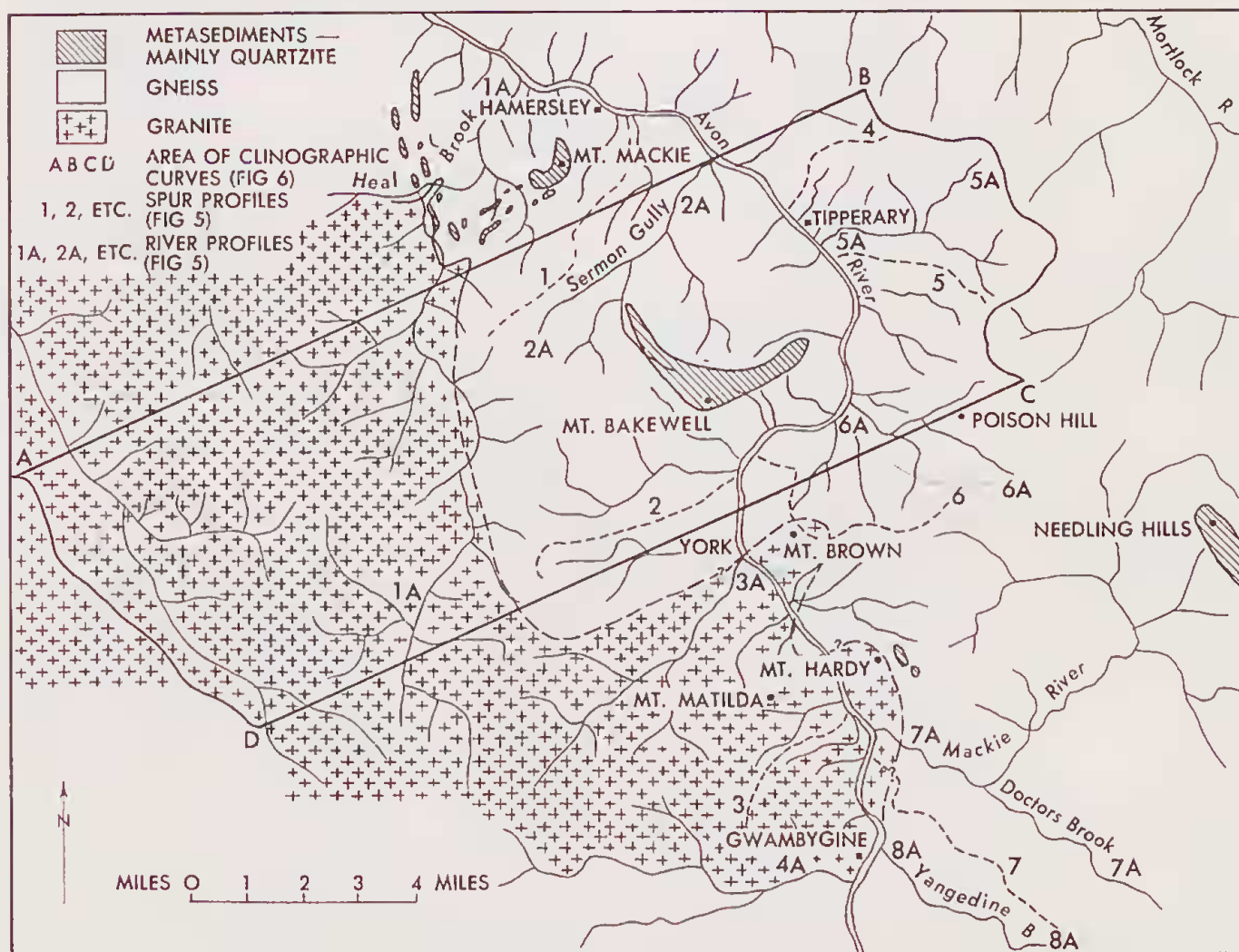


Fig. 2.—Geology and drainage.

above sea-level. West of the river, however, on the more resistant granite and meta-sedimentary rocks, remains of a laterite-capped surface which is correlated with that east of the Avon are 200 to 300 feet higher. Numerous dissected remnants, generally between 1,000 and 1,150 feet, extend from Mt. Ommanie (711657) in the north to the "Stockdale" (708472) area in the south.

Rising above the level of the deeply weathered surface are Mt. Bakewell (1,500 ft.) and the Needling Hills (1,200 + feet). Woolnough (1918) suggested that hills standing above the plateau level indicate an earlier surface which he named the "Mount Dale Level". Mt. Bakewell and the Needling Hills are satisfactorily explained as the topographic expression of resistant quartzites on the old erosion surface. There is no evidence of an earlier erosion surface in this area.

The Terraces

The deeply weathered surface has been strongly dissected by the Avon and its tributaries. Four stages are recognised between the old surface and the main channel. Corresponding to the first three stages are two rock-cut terraces and an alluvial terrace, each comprising backing "slopes" at its inner margin, furthest from the river, and lower, gently sloping "flats" as its outer margin, nearest the river. The fourth stage is represented by a later incision of the Avon and its tributaries. The break of slope between the "flat" of one terrace and the backing "slope" of the terrace below is shown on the map illustrating the distribution of remnants of the terraces (Fig. 1). The terraces can be traced almost continuously, rising upstream in the area mapped.

Terrace I.—The inner limit of the first stage of entrenchment is the breakaway which generally separates it from remnants of the deeply weathered surface. A long concave slope leads down to the terrace "flat" as much as 100 feet below. The terrace flat has been dissected into spurs with gently sloping crests, and the equivalent stage is continued into the adjacent tributary valleys by slope breaks and minor benches. The form of the Terrace I spurs is illustrated in Figure 3. Except for Spur IV, the crests are up to about 100 yards wide and 400 yards long with slopes of about 1 per cent. towards the river. Spur IV, at the head of a tributary valley, is gently rounded in cross-section with marginal slopes of 3 per cent. The margins of the crests generally slope at between 1 and 2 per cent. towards the steeper (up to 12 per cent.) flanks of the spurs. The backing slopes, leading up to and including the discontinuous breakaways of the deeply weathered surface, attain 7 per cent.

The terrace was mapped on the east side of the Avon valley, where it was seen to rise upstream and up both sides of tributary valleys. In the downstream part of the area it is generally at an altitude of 700 feet. However, below Mt. Brown it is at about 725 feet, and upstream it attains 800 feet near Quartz Hill (848518). The terrace rises away from the Avon to between 750 and 800 feet in the heads of tributary valleys, e.g., east of Ironbark farm and near Poison Hill.

Although the outer margin of the terrace occasionally coincides with outcrops of more resistant rocks it does not follow any one band for any distance and locally cuts across structure. Thus, in the tributary valleys west of Poison Hill, the terrace transgresses minor breaks of slope formed by thin bands of more resistant gneiss. Similarly, around Mt. Brown, the terrace leaves the gneiss and transgresses the granite.

The terrace was mapped in tributary valleys as well as in the main valley, as "paired" benches on both valley sides. What gradient there may be on these valley-side "flats" is towards the Avon and the remnants can be traced rising steadily up the main valley. In the tributary valley west of Poison Hill the longitudinal gradient of the old valley floor, measured from the surviving remnants of the terrace on the north side of the valley, is 2 per cent. towards the Avon.

These characteristics all point to this land form being the remains of a previous valley floor, a cyclic feature, and a distinct stage in the entrenchment of the Avon into the deeply weathered surface.

Terrace II.—This terrace occurs primarily as spur crests and also as restricted benches and slope breaks which occur on valley sides below the level of Terrace I. The spur crests are usually less than 100 yards wide and gently rounded in cross section (Fig. 3). They slope at between 1 and 3 per cent. towards the spur sides, which have gradients of up to 9 per cent. In longitudinal profile the crests slope at between 0.5 and 2 per cent. and are up to 300 yards long. The backing slopes are up to 7 per cent. but have local structural benches.

Terrace II is at an altitude of just above 600 feet in the downstream part of the area, rising to 650 feet at the head of the tributary valley in which Mobedine farm is situated. The terrace rises up the main valley and attains 700 feet south of Mt. Brown. It is also well-preserved near Hamersley (742699), extending from a mile or so east of Rivoli (736694), following the 600 feet contour westwards and rising up the valley of Heal Brook to an altitude of 650 feet west of Mt. Mackie.

Terrace II has been more closely dissected than Terrace I. Thus, it is preserved as rounded spur crests, with "flats" less typical than in Terrace I. It does, however, have the same fundamental characteristics as Terrace I. It cannot be explained by more resistant outcrops forming local base levels of denudation. Locally it cuts across them, as at Mt. Brown where it transgresses the granite boundary. In addition, the feature can be traced along both sides of tributary valleys, rising upstream. It is, therefore, interpreted as indicating a further stage of downcutting in the Avon valley.

Terrace III.—Unlike the older, rock-cut terraces, Terrace III is a depositional feature. It comprises the present valley floor of the Avon and the lower parts of tributary valley floors and represents a period of aggradation following the dissection of Terrace II. It is at an altitude of about 550 feet flanking the Avon River but rises to about 600 feet in the tributary

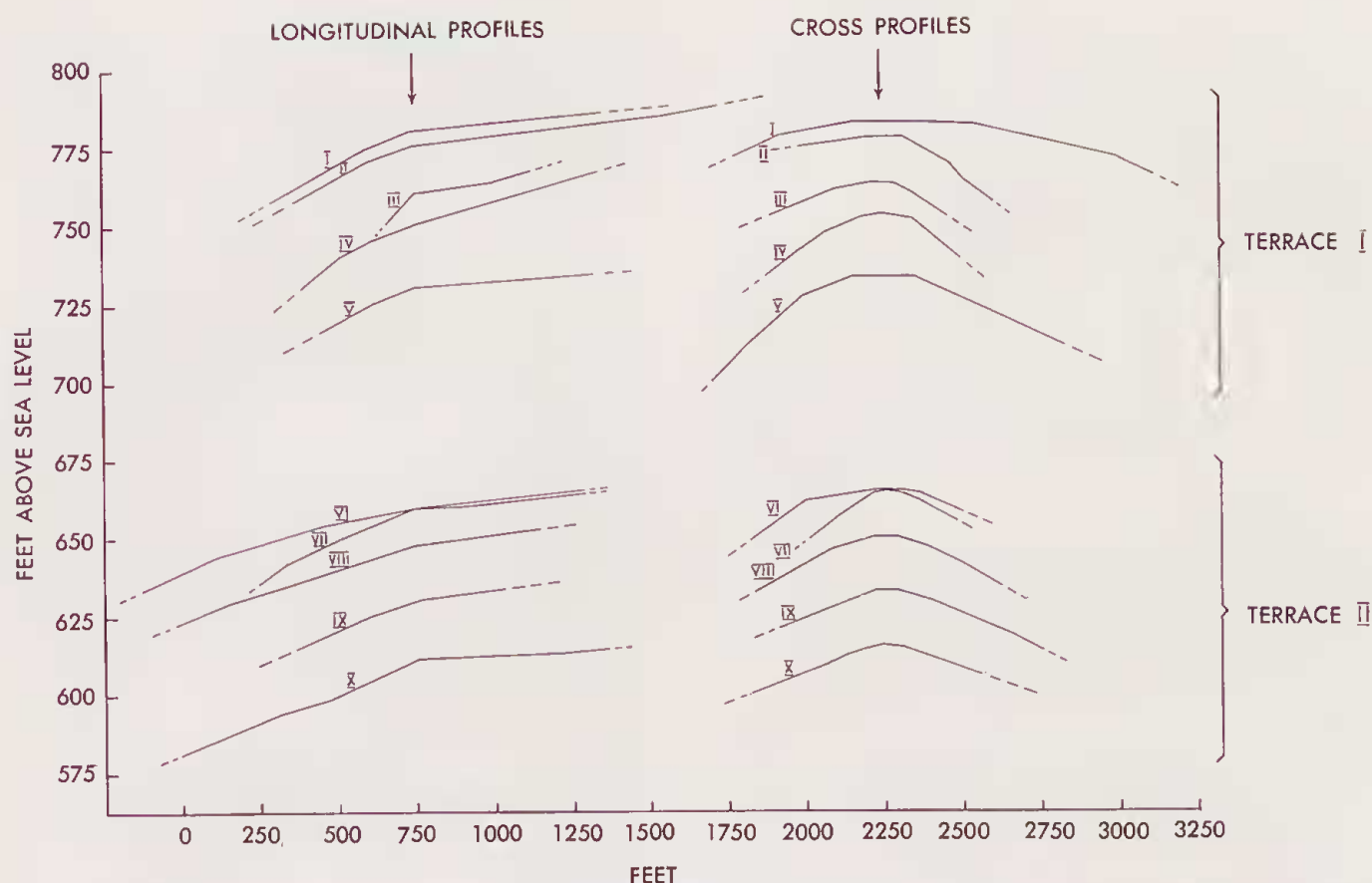


Fig. 3.—Profiles illustrating form and height range of Terrace I and Terrace II remnants (Vertical exaggeration $\times 10$). Locations shown in Fig. 2.

valleys west of Poison Hill (880601). The range in form of the terrace is illustrated in Figure 4. It extends between $\frac{1}{2}$ and 1 mile downslope and comprises outer "flats" between 100 yards and $\frac{1}{2}$ mile long with gradients of about 0.6 per cent., and backing "slopes" up to about 3 per cent.

The deposits of the terrace embrace two sub-stages—an older deposit consisting of lateritised arkosic grits being overlain unconformably by younger fine-textured alluvium (Mulcahy 1959, 1960). The maximum exposed thickness of the grits is about 6 feet but the base was not seen. The younger alluvium is up to 15 feet thick in the area of detailed field work.

In the Avon valley numerous exposures of the grits in the floors of channels incised in Terrace III suggest that they are continuous beneath the alluvium of the terrace. These grits are correlated with similar deposits, called the Mortlock beds, which occur at a high level in the upper reaches of the Mortlock River and which occupy shallowly dissected valley floors cut in Terrace I—i.e., Terrace II stage sites. However, in contrast to the more or less complete lateritic profiles in the Mortlock valley, the deposits in the Avon valley have been truncated and then reburied by the younger alluvium (Mulcahy 1959, 1960).

Thus, Terrace III stage comprises two sub-stages—the first consisting of downcutting into Terrace II and the subsequent deposition of the Mortlock beds; the second consisting of erosion and truncation of the Mortlock beds followed by the deposition of fine-textured alluvium.

The Channel and Lower Flood-plains.—The youngest phase of downcutting has reached the stage where the Avon and its tributaries are incised up to 25 feet into Terrace III, and the channel floors are cut into the weathered grits (Fig. 4). Restricted lower flood-plains are forming locally. These occur marginal to the Avon and in the lower courses of tributary streams and are typically less than 100 yards wide.

Cartographic Analysis

Cartographic analysis of the York sheet (No. 400 1 mile-series, Second Edition) was applied after field work had been completed and after the cyclic features described above had been recognised. The aim of this analysis was to determine the regional significance of these features and to illustrate their forms and their relationships to each other.

Projected Profiles

Projected profiles (Barrell 1920) were constructed for that part of the Avon valley between Gwambygine (825453) and Hamersley (742699), with parallel lines of section drawn normal to the general trend of the valley (Fig. 5a). This technique projects surface levels over a wide area into one view to attempt to illustrate the original forms of surfaces since dissected. Similarly, by projecting features related to stages of downcutting and base levelling—valley side benches and "graded" valley floors—it could

also be expected to show the relationships and distribution of such intact forms in different parts of the catchment.

The profiles were simplified and the various levels emphasised by showing only interfluvial crests, valley side benches and valley bottoms, and omitting connecting slopes.

The most striking feature on the profiles is that the "reconstructed" deeply weathered surface is shown to be considerably lower east of the river than to the west. East of the Avon it is generally 800-850 feet above sea-level, rising away from the river to 900-950 feet. However, west of the Avon this old surface is usually at 1,100-1,150 feet attaining 1,200 feet or so away from the river and sloping gently to 950 feet close to the Avon. Mt. Bakewell and the Needling Hills rise well above the general level of the surface.

The profiles illustrate Terrace I and Terrace II stages of downcutting, shown as the valley bottoms of entrenched tributary streams and the valley side benches of the Avon.

West of the Avon, Terrace I stage is indicated at about 700 feet close to the river, and by broad valley bottoms rising away from the river to 850-900 feet and more in the extreme west. East of the river this stage is reflected in benches at 700-750 feet and in the level extending eastwards at 750 feet.

Terrace II stage is seen in benches at 600-650 feet near the Avon and in broad valley bottoms at this level east of the river, rising to 700 feet in the extreme east. West of the Avon, Terrace II stage valley bottoms rise from 650 feet near the main river, reaching 800 feet in the west.

Terrace III is illustrated by the broad "flat" at 550 feet west of the river.

River and Spur Profiles

River profiles were drawn because it might be expected that, after rejuvenation, the surviving portion of an earlier profile would meet the developing new profile in a nickpoint of charac-

teristic form. If such convexities or breaks in the profile had cyclic significance they would be expected to relate to remnants of the earlier valley floors now preserved at terraces downstream from the nickpoints. Therefore, spur profiles were drawn in conjunction with the river profiles to verify whether these cyclic relations occurred. Figure 5 (b and e) shows the profiles, and their location is shown on Figure 2.

Structural differences may explain breaks in river profiles. However, in view of the highly foliated nature of the underlying rocks, it is unlikely that structural differences could cause corresponding breaks in the river profiles and levels on the spur profiles. Neither could underlying structure result in the formation of the distinct levels that characterise all the spurs.

In the western tributaries of the Avon, Terrace I stage nickpoints range in height from 750 to 950 feet, depending on how much the lower profiles of this stage have been destroyed by Terrace II rejuvenation. Nickpoints occur at 650-800 feet where Terrace III stage rejuvenation meets the Terrace II stage valley floors.

Only two nickpoints are revealed in the river profiles east of the Avon. These are at 750 feet and may represent the junctions of Terrace II stage and Terrace III stage profiles. The absence of other breaks in the streams east of the Avon may be due to more rapid regrading on the less resistant rocks of that part of the area.

The spur profiles illustrate the associated valley-side features. West of the Avon Terrace I remnants are preserved at 750-800 feet and Terrace II remnants at 650 feet on all the spurs. East of the river these stages are indicated at 700-750 feet and at 600-650 feet on the spur profiles.

Clinographic Curves (Fig. 6)

Areas between successive contours were measured and clinographic curves (Hanson-Lowe 1935) were drawn for part of the valley

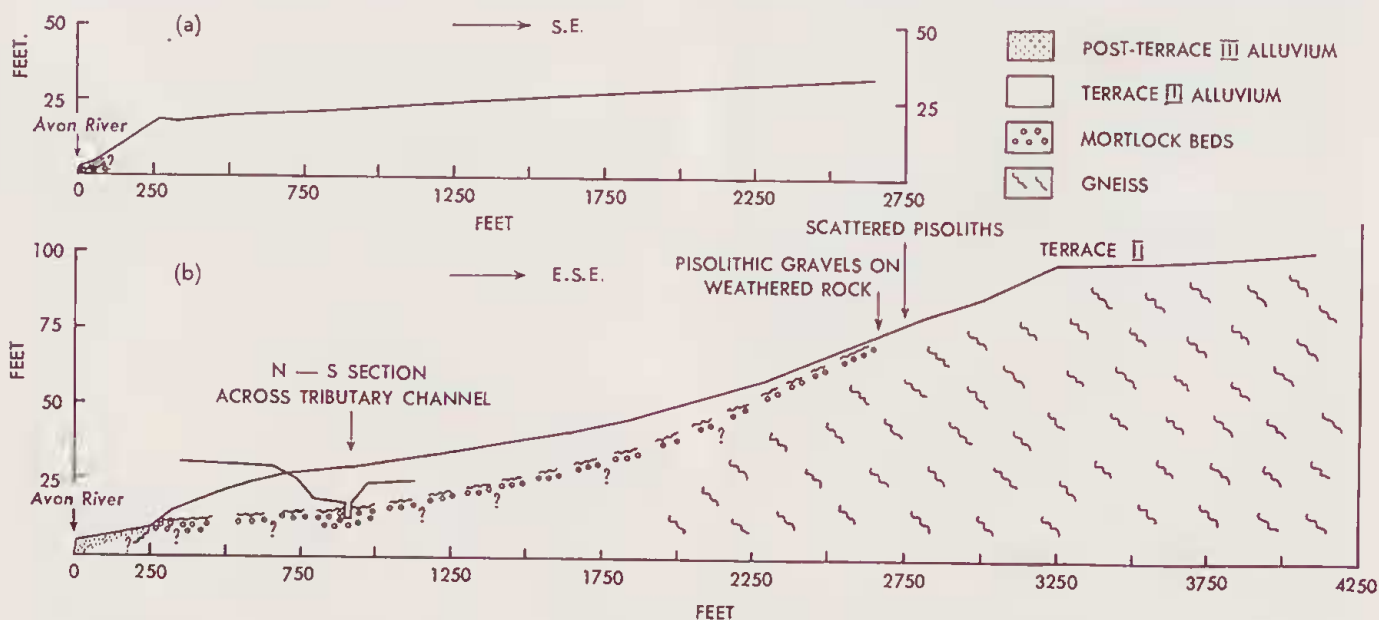


Fig. 4.—Terrace III sections showing (a) the "flat" where terrace is broad, and (b) the whole feature where terrace is narrow. (Vertical exaggeration $\times 10$). Locations shown in Fig. 2.

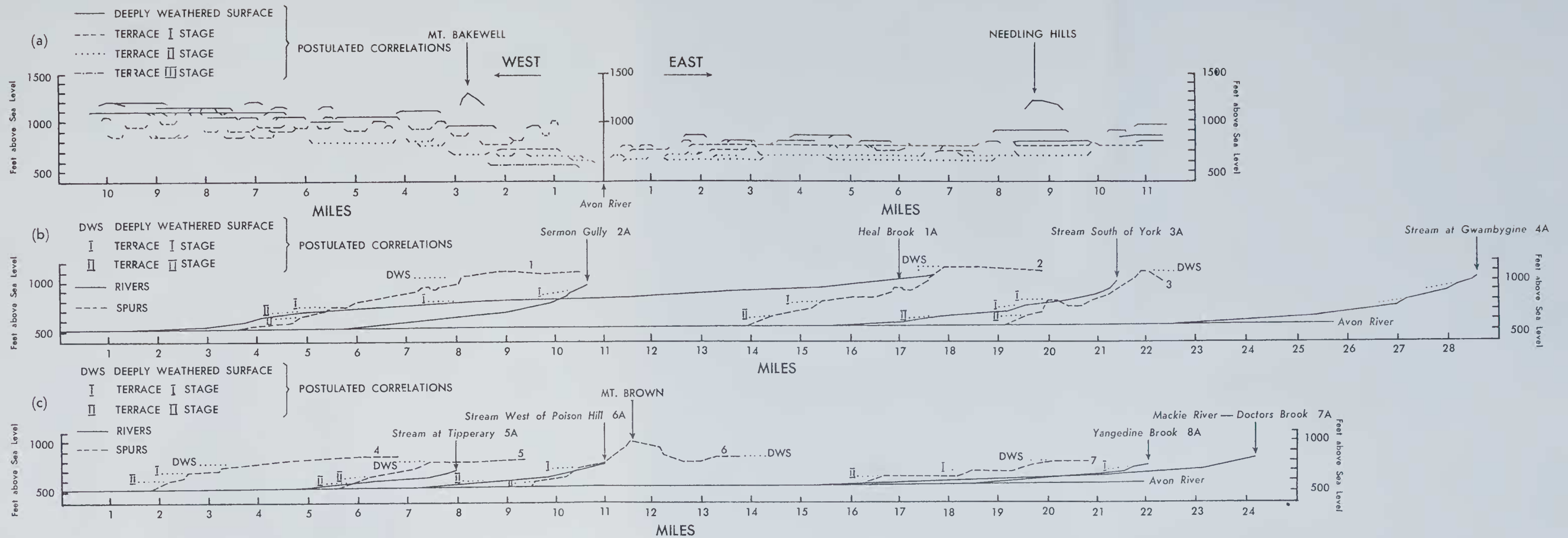


FIGURE 5. Profiles in the York area showing (a) projected profiles looking downvalley, (b) river and spur profiles west of the Avon, and (c) river and spur profiles east of the Avon. (Vertical exaggeration x 10). Locations shown in Fig. 2.



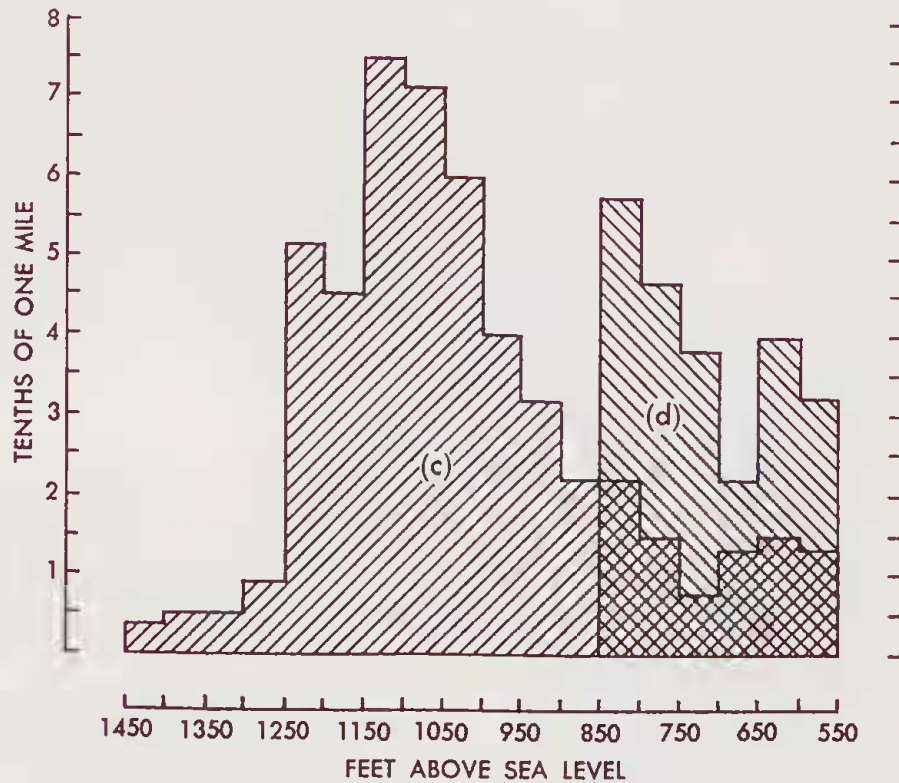
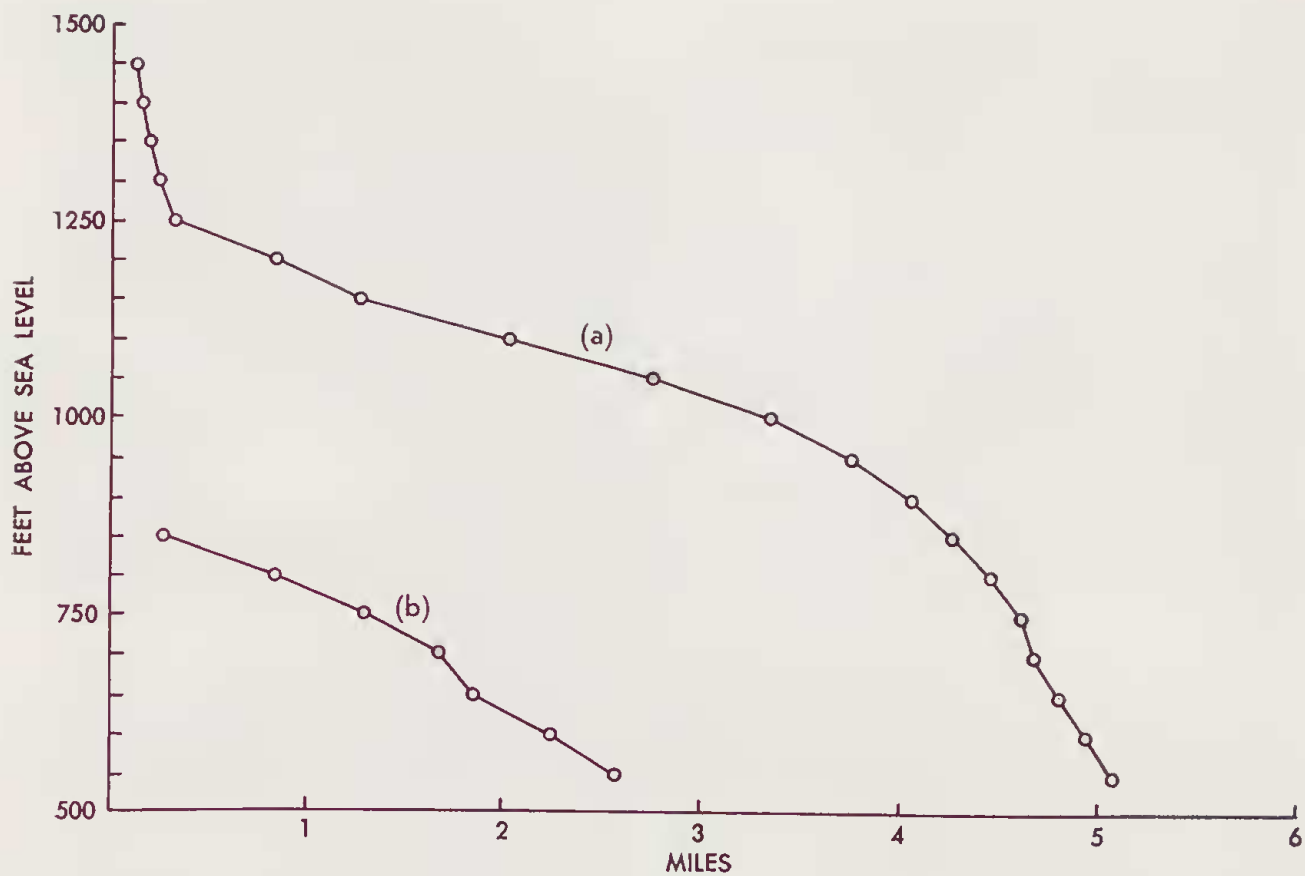


Fig. 6.—Clinographic curves (a) west of the Avon, and (b) east of the Avon. Histograms showing differences in successive radii, (c) west of the Avon, and (d) east of the Avon.

west of the Avon and part to the east (area ABCD on Fig. 2).^{*} Histograms were drawn showing the differences between successive radii used in constructing the clinographic curve.[†] These have considerable usefulness in emphasising slope changes; the convex lower margins of relatively gently sloping sectors of the curve appear as maxima, whilst the backing concavities appear as minima.

West of the Avon.—The level of the deeply weathered surface here is reflected by a gently sloping section in the clinographic curve (Fig. 6a) at 1,000-1,150 feet and by a broad maximum between these levels on the histogram (Fig. 6c). Hills above are indicated at 1,150-1,250 feet in the curve and by a slight maximum on the histogram. The top of the curve rises sharply to Mt. Bakewell, above 1,450 feet.

Terrace I stage incision into the upland surface is represented by the steepening of the curve at 1,000 feet and by decreasing column heights on the histogram. The gentler lower slopes of this stage cause a break in the continuity of decreasing column height at 800-850 feet.

The further steepening of the curve below 750 feet, and the histogram minimum at 700-750 feet mark the upper limit of Terrace II stage incision. The convexities bounding the lower slopes of this stage are indicated by a slight maximum at 600-650 feet on the histogram.

Terrace III stage downcutting is not shown by the curve or by the histogram.

East of the Avon.—The clinographic curve (Fig. 6b) indicates that there is a greater area of country at 800-850 feet than between successive contours at lower levels. The flattening of the curve at 800-850 feet probably records the existence of both deeply weathered surface remnants and Terrace I "flats". This may be due to the fact that remnants of the deeply weathered surface are small, or that the vertical interval between them and Terrace I is less than 100 feet, or that the connecting slopes between the deeply weathered remnants and Terrace I are gentle.

The steepening of the curve at 650-700 feet and the histogram minimum between these levels indicate the striking slope change associated with vigorous Terrace II stage incision. The flattening of the curve at 600-650 feet and the corresponding histogram maximum illustrate the change to the graded lower slopes of Terrace II.

A very slight steepening below 600 feet in the curve indicates Terrace III stage incision.

Land Forms and Soils

Mulcahy (1959, 1960) has correlated the soils of the area with a number of "erosional and depositional surfaces". His Quailing surface consists of a laterite which occupies the highest parts of the landscape. The Kauring surface is

^{*} In the clinographic curve the radii of circles equal in area to that within each contour (x axis) are plotted against height above sea-level (y axis) to give mean gradients.

[†] The author is grateful to J. A. Mabbutt of the Division of Land Research and Regional Survey for suggesting the construction of these histograms.

a younger laterite which occurs at a slightly lower level. The Quailing and Kauring surfaces are regarded by Mulcahy as part of the "Old Plateau" (Jutson 1934) and thus he deduces that the laterite has formed in at least two stages.

Sandy deposits derived from the Quailing and Kauring surfaces and named the Quailing depositional and Monkopen surfaces form features termed "spillways".

Mulcahy believes that rejuvenation of drainage in this area took place in response to post-Tertiary uplift and that this resulted in a number of "erosion cycles". The oldest of these is represented by the Belmunging and Mortlock surfaces. "the remnants of the sides and floors respectively, of valleys cut in the old plateau" (Mulcahy 1960, p. 211).

His second cycle is represented by the Balkuling surface which is a pediment cut in the transitional and pallid zones. It is extending by the retreat of "breakaways which bound the old plateau and the Belmunging surface and hence it must be younger than both of them" (Mulcahy 1960, p. 213).

Mulcahy's youngest "cycle of erosion" is represented by the York and Avon surfaces, the upper limit of which is marked by "a slight increase of slope" (Mulcahy 1960, p. 214) below the Balkuling surface. Mulcahy and Hingston (1961) mapped three soil types on the York surface—shallow stony soils (Y1 in Fig. 7), red-brown earths (Y2 and Y3 in Fig. 7), and poorly drained soils (Y4 in Fig. 7).

The Mobedine surface of Mulcahy occurs as a scree forming the noses of ridges at about the 600 feet contour in the Avon valley.

Summarising, therefore, Mulcahy recognises three cycles of erosion resulting from the rejuvenation of drainage whereas four stages in the downcutting of the Avon into the deeply weathered surface have been recognised in the field by the author and described above. Because of this, and in view of Mulcahy's assertion that "the field evidence, then, shows that a good correlation exists between the distribution of the soils and that of the major geomorphic surfaces, for which a relative age sequence can be established" (Mulcahy 1960, p. 215), the distribution of soils is reviewed in the light of the four stages recognised geomorphologically.

The soils as mapped by Mulcahy and Hingston (1961) and the cyclic elements recognised here in an area extending north-east from Maekies Crossing are shown in Fig. 7. Because of the complexity of this map, Fig. 8 shows typical relationships between the cyclic land forms, weathering zones, superficial deposits and soils, generalised in three dimensions for most of the area shown in Fig. 7.

The Soils of the Deeply Weathered Surface

The Quailing laterite is found on the higher and lower parts of the largest remnant of the deeply weathered surface east of Ironbark farm, with the Quailing and Monkopen depositional materials essentially on the slopes fringing the higher part and extending down into the heads of dissecting streams. The sites of the Kauring

laterite are at the margins of the Ironbark residual, in areas of waxing slope development. On the north and east they occur immediately above the dissection heads of tributaries of the Mortlock River. The Belmunging soil surface also occurs on the lower parts of the Ironbark residual but extends downslope transgressing the boundary of the remnant. The other remnants of the deeply weathered surface typically carry only the Quailing laterite with some Quailing depositional sands but the Balkuling and Belmunging soil surfaces, with exposures of weathered rock, are found on the remnant immediately north-west of Poison Hill.

Terrace I Soils

Terrace I stage sites carry a variety of soils. In that part of the area drained by the Mortlock headwaters, the Belmunging soil surface occurs extensively on the inner slopes below remnants of the deeply weathered surface, generally where these are not bounded by breakaways. Good examples are found immediately north and south of the Ironbark residual and on slopes marginal to the Collins Hill residual.

Immediately south of the Ironbark residual of the deeply weathered surface there is a small outlying remnant of the Quailing laterite which forms a bench on Terrace I. Here, therefore, the terrace must be cut in the uppermost parts of the old deep weathering profile.

The Balkuling soil surface is found downslope from remnants of the deeply weathered surface but is usually separated from these by breakaways. The soils have as their parent material the pallid zone of the Quailing and Kauring laterites or weathered rock. They occur on pediments below the breakaways occasionally extending downslope on to spur crests formed by the remains of Terrace I "flats", particularly east and south-east of Mt. Brown. Here, at the heads of tributary valleys, the base level for Terrace I downcutting was within the pallid and transitional zones of the weathering profile. Elsewhere, however, Terrace I downcutting proceeded below the depth of weathering and in these situations the York red-brown earths generally occur on the lower parts of the terrace, where it is cut on unweathered rock. In addition, Terrace I has locally been closely dissected into rounded spurs at the heads of tributary valleys, and these remnants carry the shallow stony variety of the York soils (e.g., profile IV, Fig. 3).

Terrace II Soils

Terrace II sites in the Avon valley are mainly characterised by the shallow stony soils which form part of the York soil surface, and these occasionally extend up to the inner slopes. However, York red-brown earths also occur on the terrace. Certain tributary valley heads of this stage of downcutting are the principal sites of the poorly drained variety of the soil comprising the York soil surface. York red-brown earths also locally occur in the floors of these tributary valleys.

In addition, the Belmunging soil surface occurs on certain Terrace II sites in the headwaters of the Mortlock, mainly the inner slopes

of the terrace. This is well illustrated one and a half miles north-east of Poison Hill on the slopes below a large remnant of Terrace I (903620). These sites are often less than 50 feet above the main tributary channel and locally the Belmunging soil surface extends down on to gentle slopes only a few feet above, and 100 yards or less from the channel. In the more dissected valley of the Avon, where post-Terrace II stage downcutting and base levelling is much further advanced, similar Terrace II sites (without Belmunging soils) are about 100 feet above the main channel.

The Mortlock surface occurs downslope from the Belmunging surface in the floors of the Mortlock and its tributaries, which have been interpreted as shallowly dissected Terrace II stage "flats".

In this area, the deposits of the Monkopen soil surface are associated with the Ironbark residual of the deeply weathered surface. They originate on the residual and "spill" out through the breakaways to occupy pre-existing valleys cut through Terrace I. To the south-east of this residual, however, the deposits spread out on to the low interfluvies between the valleys and extend down on to the gentle lower slopes, cut during Terrace II stage. They also locally overlie the restricted slopes cut during Terrace III stage incision.

All the spillways in the present area, with one exception, are confined to the Mortlock headwaters. The exception is a small spillway at the head of the Avon tributary which flows past Ironbark farm (862653).

Terrace III Soils

The most extensive soil type associated with Terrace III is the alluvium of the terrace itself—the solonized grey or brown soils of the Avon surface. Exposures of underlying grits in tributary channels incised in to the terrace form part of the Mortlock surface.

The Mobedine surface occurs at the inner margin of Terrace III in the Avon valley. It is found on the slopes below the noses of spurs, the crests of which are Terrace II remnants.

Lastly, areas of the York soil surface, mainly the shallow stony soils but locally also the red-brown earths and poorly drained soils, occur in tributary valleys on the floors and adjacent slopes cut during Terrace III stage downcutting.

Discussion

The limited distribution of the Quailing and Kauring laterite residuals in this area makes any ambitious interpretations impossible. From the geomorphological evidence they could satisfactorily be regarded as the remains of an undulating surface on which the Quailing laterite developed and subsequently underwent varying degrees of stripping. In the area of detailed field work, the Kauring laterite is found above Terrace I stage dissection heads or in other areas of waxing slope development, that is, on sites where the Quailing laterite has been truncated. These sites would appear, therefore, to be related to the advance of Terrace I stage downcutting into the surviving remnants of the deeply weathered surface. Alternatively,

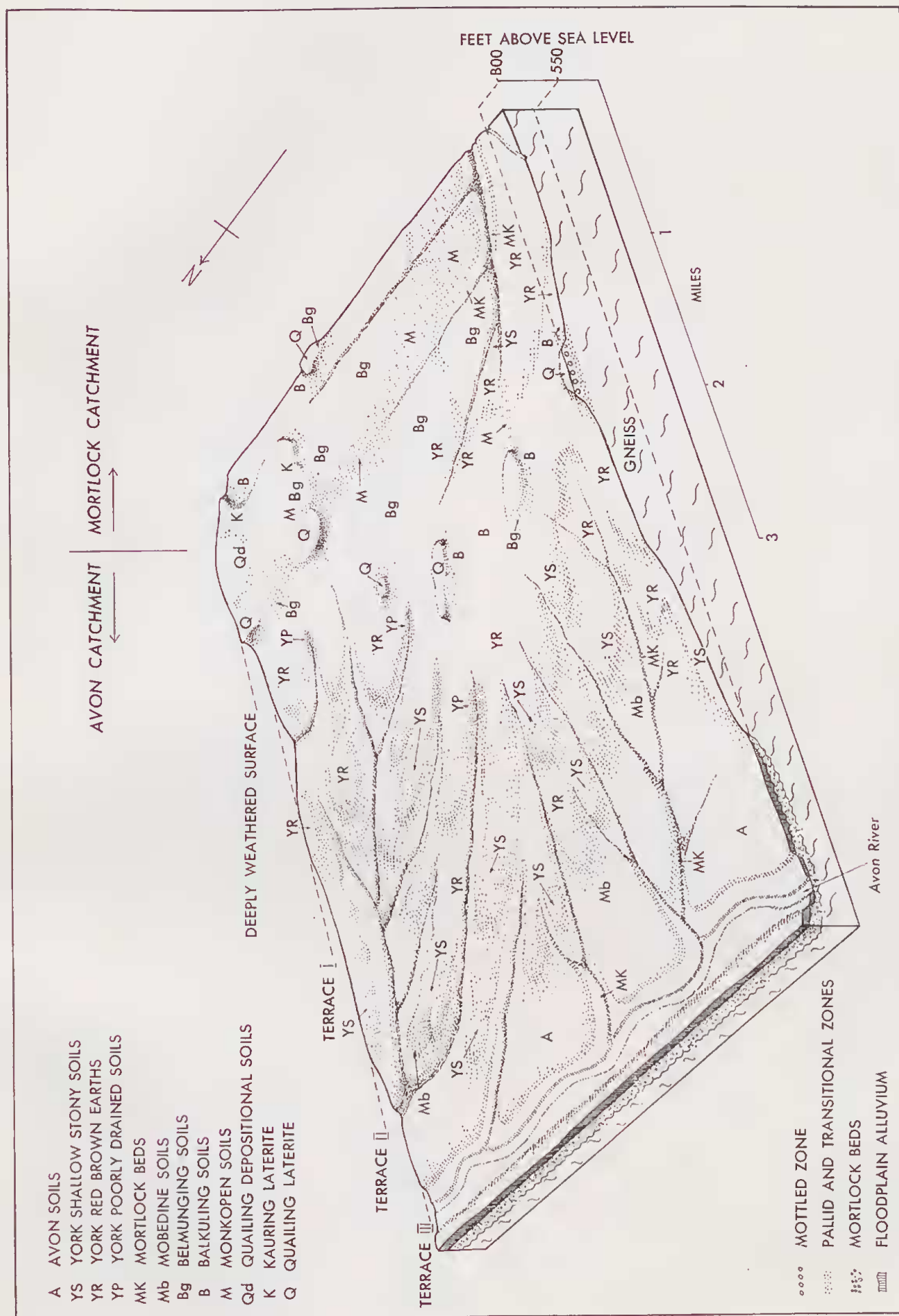


Fig. 8.—Relations between cyclic land forms, weathering zones, superficial deposits and soils as mapped by Mulcahy, generalized for the area shown in Fig. 7.

a pre-Terrace I stage of downcutting could be invoked to explain the truncation of the older laterite. However, there is no geomorphological evidence to suggest this and the first hypothesis is favoured.

Remnants of the Quailing and Kauring laterites show distinct and restricted occurrences on the watershed between the Avon and Mortlock Rivers. The geomorphic relationships of the younger soil surfaces are more complex and they are not necessarily restricted to any of the cyclic surfaces recognised here. This is illustrated by the extension of the Belmunging and Monkopen soil surfaces from the deeply weathered surface across Terrace I and Terrace II and on to younger sites.

The degree of truncation of the weathering profile has influenced subsequent soil development on Terrace I sites. Balkuling soils occur where the terrace is cut in weathered rock; downslope, where it is cut on unweathered rock, York red-brown earths are found.

The formation of the spillways probably indicates conditions of surface instability such as would be induced by a change to drier conditions resulting in a reduced vegetation cover. This would lead to the movement of sandy material from remnants of the deeply weathered surface into the upper parts of tributary valleys and to a reduction in the competence of streams to carry away the derived material.

The occurrence of more than one band of ferruginous concretions within the deposits possibly indicates a number of depositional "periods" separated by soil forming "periods" (Mulcahy 1959, p. 46).

The only geomorphological evidence for the age of the spillways is that the bulk of the deposits occur in valleys cut through Terrace I but that the youngest sites on which they occur are the slopes cut below Terrace II. Therefore, they are mainly post-Terrace I in age, whilst the youngest deposits at least formed during Terrace III stage. On geomorphological grounds, therefore, it is possible that the spillway deposits are, in part at least, linked with the Mortlock deposits. Some support is given to this by the contiguity of the spillway and Mortlock deposits in many parts of the Mortlock valley as mapped by Mulcahy. The coarse arkosic sediments of the Mortlock surface also indicate an extensive aggradational phase and may be due to the same change to increased aridity postulated to have resulted in the deposition of the spillways. In the Avon valley this aggradational phase is dated as part of Terrace III stage, although equivalent deposits and the tributary spillways occur on Terrace II stage sites in the upper reaches of the Mortlock. However, Mulcahy has emphasised the multiple nature of the spillway deposits and it is entirely feasible that the spillways may have operated at all stages in the destruction of the deeply weathered surface, from Terrace I stage onwards. Therefore, the formation of the spillways is not restricted to any geomorphological stage in the concluding denudation chronology.

The Mortlock deposits have been subsequently lateritised. The greater degree of weathering of these deposits compared with those of the

spillways could partly reflect site differences—the Mortlock deposits occur on relatively poorly drained valley floors whereas the spillways occupy more freely drained tributary valleys. In addition, the spillway sands being derived from the old laterites might not be capable of further weathering, whereas much of the Mortlock deposits were no doubt derived from valley sides downslope from the old laterites and would, therefore, contain material which would weather readily.

The Belmunging surface could have developed on the valley sides during this second period of lateritisation. It is noteworthy that the Belmunging surface is absent from the Avon valley. Firstly, this may be because it was never well developed on the steeper slopes of the more dissected Avon valley, although in fact there are numerous "flats" and gentle slopes where it could have done so.

Secondly, subsequent rejuvenation and dissection, which have been very active in the Avon valley, could have removed all trace of the Belmunging surface. This same rejuvenation has not yet attacked the headwater areas of the Mortlock to the same extent and Belmunging remains are preserved there. The truncation of the Mortlock layer beneath the alluvium in the Avon valley testifies that such erosion has in fact occurred. The pisolithic gravels of the Mobedine surface and the scattered pisoliths which occur upslope from it (Fig. 4b) may have been derived from a soil which was related to the Belmunging surface and which has been removed from the Terrace II "flats" above. However, the Mobedine gravel is different from that of the Belmunging surface (Mulcahy, personal communication).

Lastly, the Belmunging surface in the Mortlock catchment may be associated with part of the truncated deeply weathered profile—and the greater part of the Avon valley is cut below the level of that zone of weathering.

Thus, the pattern of soils in the York area indicates that a phase of surface instability, probably due to the change to more arid conditions, occurred during a first Terrace III sub-stage. This could have resulted in the accumulation of the Mortlock materials and of much of the spillway deposits. The Belmunging, Mobedine and Mortlock surfaces, and possibly the Kauring laterite, could indicate a younger weathering phase. The erosion which truncated the Mortlock profile in the Avon valley during the second Terrace III sub-stage may have removed the Belmunging surface and the spillways from the valley. As a result the York surface and the related Avon deposits formed extensively in the Avon valley and locally in the Mortlock valley.

Conclusions

In contrast to the three "cycles" of erosion described by Mulcahy (1960, p. 211) and the two "cycles" he writes of most recently (Mulcahy and Hingston 1961, p. 32), here, four stages are recognised in the downcutting of the Avon into the deeply weathered surface. Obviously, therefore, soil surfaces cannot be identified with cycles of erosion as implied